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Advances in the Study on the Fermentation Characteristics of Edible Fungus Polysaccharides and Their Interaction with Intestinal Microflora

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Abstract

With the in-depth study of intestinal flora, it is found that the changes of its structure and function are closely related to the occurrence of diseases.Edible fungi are natural resources, and polysaccharides are the main active components. The research found that most of the mushroom polysaccharides want to be used by the human body, they need to be fermented by the intestinal flora first. In this paper, we summarize the research on the improvement of host capacity of mushroom polysaccharides in recent years, so that we can have a deeper understanding of the interaction between mushroom polysaccharides and intestinal flora.

Keywords: edible fungi，Polysaccharide，Intestinal flora.

Chapter 1 Preface

Among approximately 15,000 species of fungi distributed worldwide, around 2,000 are edible. In China, there is a long-standing tradition of culinary and medicinal use, with over 1,000 species of edible fungi documented, which has drawn significant attention to these organisms [1].

1.1 Overview of Edible Fungal Polysaccharides

Edible fungi serve as both food and medicine, possessing unique aroma and taste, and contain various pharmacological activities with almost no toxic side effects [2]. They are low in fat and calories but rich in health-beneficial polyunsaturated fatty acids [3], proteins, polysaccharides, polyphenols, terpenoids, amino acids, sterols, nucleosides, and other nutritional and bioactive components [4]. Additionally, edible fungi produce secondary metabolites with a range of beneficial properties. These bioactive secondary metabolites or nutrients are increasingly being extracted, encapsulated, or compressed into tablets as functional dietary supplements or modulators [5]. Regular intake of these supplements can enhance immune function, thereby improving disease resistance and promoting faster recovery. They exhibit various health benefits, including antioxidant, antibacterial, anti-inflammatory, hypoglycemic, antitumor, immunomodulatory, and neuroregulatory effects [6–10].

Polysaccharides are widely distributed in nature and possess diverse biological activities. They serve as important regulators with physiological functions such as immunomodulation [11–13], anticancer effects [14–16], anti-inflammatory properties [17], antioxidant activity [18, 19], and hypoglycemic effects [20, 21].

1.2 Fermentation Characteristics of Edible Fungal Polysaccharides

For most edible fungal polysaccharides to be utilized by the human body, they must first undergo fermentation by gut microbiota, and the resulting metabolites exert various physiological functions [22]. Gut microbiota secrete different enzymes to ferment polysaccharides, producing short-chain fatty acids (SCFAs), including formic acid, acetic acid, propionic acid, and butyric acid, which lower intestinal pH, inhibit the proliferation of harmful bacteria, and enhance intestinal mucosal immunity [23]. In turn, polysaccharides can improve intestinal integrity, alleviate mucosal damage, increase SCFA production, reduce metabolic endotoxins, downregulate inflammatory factors, and upregulate tight junction protein expression [24].

For example, polyglucose, polygalactose, and polymannose—composed of glucose, galactose, and mannose—can be fermented by gut microbiota to generate SCFAs, thereby promoting the proliferation of beneficial bacteria and inhibiting the growth of harmful bacteria [25, 26].

Chapter 2 Regulatory Effects of Different Edible Fungal Polysaccharides

2.1 Pleurotus eryngii Polysaccharides

2.1.1 Overview of Pleurotus eryngii

Pleurotus eryngii, also known as king trumpet mushroom, belongs to the phylum Basidiomycota, class Agaricomycetes, order Agaricales, family Pleurotaceae, and genus Pleurotus. It is widely cultivated in many countries across Southern Europe, North Africa, and Central Asia, and is primarily distributed in China's Zhejiang, Jiangsu, Sichuan, Qinghai, and Taiwan provinces. Pleurotus eryngii possesses a unique aroma reminiscent of almonds and abalone, with tender flesh and rich nutritional value. Modern pharmacological and nutritional studies have demonstrated that it exhibits various bioactive properties, including antioxidant, antitumor, immunomodulatory, antihypertensive, and cholesterol-regulating effects [27–35].

2.1.2 Interaction Between Pleurotus eryngii Polysaccharides and Gut Microbiota

In a study by Wei Hua et al. [36] on the lipid-lowering effects of Pleurotus eryngii mycelium solid-fermented polysaccharides and their impact on gut microbiota, it was found that these polysaccharides could restore gut microbiota dysbiosis induced by a high-fat diet. Specifically, they significantly promoted the growth of Lactobacillus (a core gut microbiota and important probiotic in traditional research) within the Firmicutes phylum while inhibiting Staphylococcus and Aerococcus (Firmicutes) as well as Corynebacterium (Actinobacteria). Additionally, they enhanced the abundance of Bacteroides (Bacteroidetes), Firmicutes, and Actinobacteria while suppressing certain Firmicutes populations. Furthermore, Pleurotus eryngii polysaccharides improved the dysregulated carbohydrate and amino acid transport and metabolism functions in gut microbiota caused by a high-fat diet, restoring a balanced state where carbohydrate metabolism regained dominance.

In another study by Ma Gaoxing et al. [37] on the intestinal effects and mechanisms of Pleurotus eryngii polysaccharides, intake of these polysaccharides significantly increased the concentrations of acetic acid, propionic acid, isobutyric acid, n-butyric acid, and isovaleric acid in the cecum of mice, as well as isovaleric acid and n-valeric acid in the colon. Moreover, Pleurotus eryngii polysaccharides reduced intestinal pH, increased water content, and improved fecal volume, thereby promoting intestinal health. At the phylum, class, order, and family levels, these polysaccharides altered the diversity of fecal microbiota:

At the phylum level, Firmicutes abundance decreased significantly, while Bacteroidetes increased.
At the class level, Bacteroidia and Bacilli abundances rose, whereas Clostridia declined.
At the order level, abundances of Bacteroidales and Lactobacillales increased, while Clostridiales decreased.
At the family level, Porphyromonadaceae, Rikenellaceae, Bacteroidaceae, and Lactobacillaceae populations expanded significantly.

These modifications enhanced immune function and improved intestinal health.

2.2 Hericium erinaceus Polysaccharides

2.2.1 Overview of Hericium erinaceus

Hericium erinaceus, commonly known as lion's mane mushroom, belongs to the Fungi kingdom, Hericiaceae family, and Hericium genus. This fungus has several subspecies, such as Hericium caput-medusae and Hericium laciniatum. It is widely distributed throughout the Northern Hemisphere, including Europe, Asia, and North America. In China, it is primarily found in the broad-leaved and coniferous forests of Northeast China, the Lesser Khingan Mountains, and the Northwest and Southwest regions. Hericium erinaceus is known for its various health benefits, including cholesterol reduction, immune enhancement, gastrointestinal protection, anticancer properties, and anti-aging effects [38–46].

2.2.2 Interaction Between Hericium erinaceus Polysaccharides and Gut Microbiota

In a study by Yang Yang et al. [47] on the improvement of gut microbiota and immune function by Hericium erinaceus polysaccharides, treatment with these polysaccharides led to an increase in the abundance of Firmicutes and a decrease in Bacteroidetes. Additionally, the abundances of Verrucomicrobia and Proteobacteria also increased. During the fermentation of polysaccharides, short-chain fatty acids (SCFAs) such as acetic acid, isovaleric acid, lactic acid, and butyric acid were produced. This indicates that gut microbiota can further utilize Hericium erinaceus polysaccharides through fermentation, generating SCFAs that help maintain and improve host functions and intestinal health.

In another study by Baoming Tian et al. [48], it was found that after fermentation by gut microbiota, Hericium erinaceus polysaccharides significantly increased the levels of SCFAs, including acetic acid and propionic acid, leading to changes in pH that benefit overall health. Additionally, the relative abundances of Firmicutes, Bacteroidetes, and Actinobacteria increased, while that of Proteobacteria decreased. Furthermore, the relative abundances of SCFA-producing bacteria, such as Bifidobacterium, Faecalibacterium, Blautia, Butyricicoccus, and Lactobacillus, were enhanced. In contrast, the relative abundances of pathogenic bacteria, including Escherichia-Shigella, Klebsiella, and Enterobacter, were reduced. These changes promote intestinal digestion, alleviate gastrointestinal discomfort, and enhance human health.

2.3 Ganoderma lucidum Polysaccharides

2.3.1 Overview of Ganoderma lucidum

Ganoderma lucidum, belonging to the Basidiomycetes class, Polyporaceae family, and Ganoderma genus, is renowned as the "divine mushroom" and "herb of immortality" in traditional Chinese culture. There are currently 100 species of Ganoderma fungi recorded in China, with 69 species classified under the Ganoderma genus. With a medicinal history spanning over 2,000 years in China, Ganoderma lucidum is celebrated for its ability to strengthen vital energy, nourish the body, and promote longevity [49–53].

2.3.2 Interaction Between Ganoderma lucidum Polysaccharides and Gut Microbiota

In a study by Ding Qiao et al. [54], intake of black Ganoderma lucidum polysaccharides was found to significantly increase the levels of acetic acid, propionic acid, n-butyric acid, and total SCFAs. It also notably enhanced metabolic pathways related to carbohydrate metabolism and absorption, mineral absorption, and polysaccharide synthesis and metabolism. Additionally, it increased the abundance of Bifidobacterium while decreasing Enterococcus. Through in vivo fermentation producing SCFAs and lowering intestinal pH, along with modulating the composition of gut microbiota and key bacterial genera, these polysaccharides further exerted beneficial effects on diabetic rats.

In research by Chen et al. [55], Ganoderma lucidum polysaccharide intake reduced the abundances of Aerococcus, Ruminococcus, Corynebacterium, and Proteobacteria, while increasing levels of Blautia, Dehalobacterium, Parabacteroides, and Bacteroides. This restored disrupted metabolic functions in rat gut bacterial communities, including amino acid metabolism, carbohydrate metabolism, inflammatory substance metabolism, and nucleic acid metabolism.

Chang et al. [56] demonstrated that Ganoderma lucidum polysaccharide consumption decreased the Firmicutes-to-Bacteroidetes ratio and reduced levels of endotoxin-containing Proteobacteria, thereby alleviating inflammation and insulin resistance. It also maintained intestinal barrier integrity and diminished metabolic endotoxemia.

2.4 Flammulina velutipes Polysaccharides

2.4.1 Overview of Flammulina velutipes

Flammulina velutipes, commonly known as golden needle mushroom or enoki mushroom, is characterized by its golden-yellow color and slender, needle-like stipe. Taxonomically, it belongs to the phylum Basidiomycota, subphylum Agaricomycotina, class Agaricomycetes, order Agaricales, and family Physalacriaceae. This edible fungus possesses various health benefits including antioxidant and anti-aging effects, immune enhancement, and lipid-lowering properties [57-60].

2.4.2 Interaction Between Flammulina velutipes Polysaccharides and Gut Microbiota

In the study by Su Anxiang et al. [61], Flammulina velutipes polysaccharides were found to modulate gut microbiota structure through multiple mechanisms:

At the phylum level: Increased abundance of Bacteroidetes and Actinobacteria while decreasing Firmicutes and Proteobacteria
At the family level: Significantly elevated Bifidobacteriaceae and Bacteroidaceae while reducing Enterobacteriaceae
At the genus level: Enhanced Bifidobacterium, Bacteroides, and Clostridium populations while suppressing Escherichia-Shigella

The polysaccharides promoted production of short-chain fatty acids (SCFAs) including acetic acid, propionic acid, butyric acid, isobutyric acid, valeric acid, and isovaleric acid, consequently lowering the fermentation system's pH and influencing microbial metabolism. Notably, the affected bacterial genera demonstrated neurological relevance:
Bifidobacterium, Bacteroides and Butyricimonas influenced N-acetylaspartate (NAA) levels in brain tissue - a marker of neuronal health
Ruminococcus showed correlation with brain NAA levels
Butyricimonas produced butyrate with anti-inflammatory and gut-protective effects

These findings suggest Flammulina velutipes polysaccharides may regulate the nervous system through gut microbiota interactions, showing potential for improving neurodegenerative conditions.

In Qiongxin Liang et al.'s research [62], the polysaccharides increased microbial diversity and improved community structure by:

Reducing Firmicutes abundance

Increasing Bacteroidetes proportion
Elevating acetic, propionic and butyric acid levels
This modulation of SCFA production helped regulate inflammatory cytokines, potentially reducing intestinal inflammation and tumorigenesis while promoting gut homeostasis.

2.5 Cordyceps sinensis Polysaccharides

2.5.1 Overview of Cordyceps sinensis

Cordyceps sinensis is a complex consisting of the larval corpse of insects from the Hepialidae family (Lepidoptera) parasitized by the fungus Ophiocordyceps sinensis (family Clavicipitaceae). Modern research has proven that Cordyceps sinensis provides significant health benefits to the body's circulatory system, immune system, hematopoietic system, cardiovascular system, respiratory system, and glandular system. It possesses various bioactive properties including immune enhancement and regulation, anti-aging, antitumor, antibacterial, and antioxidant activities [63-67].

2.5.2 Interaction Between Cordyceps sinensis Polysaccharides and Gut Microbiota

In the study by Chen Shuping et al. [68], the relative abundances of Dehalobacterium, Coprococcus, Oscillospira, and Desulfovibrio in the intestines of mice treated with natural Cordyceps sinensis polysaccharides significantly increased, while the relative abundance of Bilophila decreased. The treatment also elevated the levels of acetic acid, propionic acid, butyric acid, and valeric acid in the cecum of colitis mice. These effects alleviated colitis by enhancing the intestinal barrier, increasing SCFA levels, inhibiting the activation of the NF-κB inflammatory pathway, and regulating gut microbiota dysbiosis.

In the study by Mengxi Ying et al. [69], Cordyceps sinensis polysaccharides improved the diversity of the gut microbial community and modulated the overall structure of the gut microbiota in cyclophosphamide-induced mice with intestinal mucosal immunosuppression and microbial dysbiosis. The treatment increased the abundance of beneficial bacteria (Lactobacillus, Bifidobacterium, Bacteroides) and reduced the abundance of pathogenic bacteria (Clostridium). Additionally, acetic acid and butyric acid were the two SCFAs most significantly elevated by Cordyceps sinensis polysaccharides. These findings confirm the potential of Cordyceps sinensis polysaccharides as a prebiotic to restore gut microbiota by improving microbial community diversity, regulating microbial structure and composition, and correcting dysbiosis. The treatment also mitigated the side effects of cyclophosphamide-induced intestinal mucosal immunosuppression and microbial imbalance on gut mucosal immunity and microbiota.

2.6 Silver Ear Polysaccharides

2.6.1 Brief Introduction to Tremella Fuciformis

Tremella fuciformis, also known as snow ear or white wood ear, is the fruiting body of Tremella fuciformis fungi in the Basidiomycota phylum and is hailed as the king of fungi. Traditional Chinese medicine holds that Tremella fuciformis has the medicinal effects of nourishing Yin, moistening the lungs, and beautifying the complexion [70-78].

2.6.2 Interaction between Tremella fuciformis polysaccharides and intestinal flora

In the study of Gang He[79] et al., it was found that feeding tremella fuciformis polysaccharides improved the intestinal flora, mainly by increasing diversity. The relative abundance of the Thick-walled bacteria phylum increased significantly, while that of the Bacteroidetes phylum decreased significantly, resulting in a significant increase in the ratio of thick-walled bacteria phylum to Bacteroidetes phylum. The intervention of Tremella fuciformis polysaccharides reversed the changes in the intestinal flora, especially the microorganisms related to obesity, such as Muribaculaceae, Lachnospiraceae, Alistipes, Bilophila and Desulfovibrio. After feeding Tremella fuciformis polysaccharides, the contents of acetic acid, propionic acid and butyric acid increased significantly, while the content of valeric acid did not change significantly. In addition, the intervention of Tremella fuciformis polysaccharides also affected the changes in BCFAs content, mainly manifested as a significant increase in isobutyric acid content, while there was no significant change in isovaleric acid content. This reversed the imbalance of intestinal flora and reduced the weight gain, fat accumulation, inflammation, hyperglycemia and hyperlipidemia in mice caused by a high-fat diet.

In the study of Lingna Xie[80] et al., it was found that feeding Tremella fuciformis polysaccharide allogeneic bacteria and Prevotellaceae-UCG-001 significantly increased, while the intestinal flora AD3011_group and Clostridia_UCG-014 in mice significantly decreased. It indicates that the treatment with Tremella fuciformis polysaccharides in mice significantly regulates the composition of the intestinal microbiota and restores the reduction in the levels of acetate, propionate, butyrate, isobutyrate, valerate and isovaleric acid. These findings suggest that the regulation of SCFAs derived from intestinal microbiota by tremella fuciformis polysaccharides may help alleviate dermatitis.

Chapter 3　Conclusions and Prospects

Most polysaccharides from edible fungi need to be digested by the intestinal flora before they can be utilized by the human body. With the development of human society, people are paying more and more attention to health. Edible fungi, as a natural resource, are both food and medicine. They have a unique aroma and taste, and contain various pharmacological activities with almost no toxic side effects. Edible fungi have a low fat content and low calories, and are rich in nutrients and active components beneficial to health, such as polyunsaturated fatty acids, proteins, polysaccharides, polyphenols, terpenoids, amino acids, sterols, and nucleosides. In addition, edible fungi contain secondary metabolites, which possess a series of beneficial properties. The bioactive secondary metabolites or nutrients produced by these are increasingly being extracted and encapsulated or taken into tablets as functional dietary supplements or regulators. Regular intake of these supplements can enhance the body's immune function, thereby strengthening the body's resistance to diseases and facilitating a faster recovery. It is precisely for these reasons that it has received extensive attention from researchers. People have begun to notice the regulatory role of edible fungus polysaccharides in our bodies and the ways and methods of their effects. Through continuous exploration, the significant regulatory role of edible fungus polysaccharides in human body functions and diseases has been discovered, laying a solid foundation for the future use of edible fungus polysaccharides as drugs to treat diseases in our bodies.

References

[1] Guan Yingxian, et al., Research Progress of Fermented Food from Edible Fungi. Food Industry Science and Technology: p. 1-13.

[2] Wei Qi, et al., Research Progress on the Lipid-lowering activity and Mechanism of Edible Fungus Polysaccharides. Food Science and Technology, 2021. 46(09): p. 190-194.

[3] Muszynska, B., et al., Anti-inflammatory properties of edible mushrooms: A review. Food Chem, 2018. 243: p. 373-381.

[4] Assemie, A. and G. Abaya, The Effect of Edible Mushroom on Health and Their Biochemistry. Int J Microbiol, 2022. 2022: p. 8744788.

[5] Sun, Y., et al. A Review of Development and Utilization for Edible Fungal Polysaccharides: Extraction, Chemical Characteristics, and Bioactivities. Polymers, 2022. 14, DOI: 10.3390/polym14204454.

[6] Gao, X., et al., Structural characterization and immunomodulatory activity of a water-soluble polysaccharide from Ganoderma leucocontextum fruiting bodies. Carbohydr Polym, 2020. 249: p. 116874.

[7] Li, X., et al., Ganoderiol F purified from Ganoderma leucocontextum retards cell cycle progression by inhibiting CDK4/CDK6. Cell Cycle, 2019. 18(21): p. 3030-3043.

[8] Shang, X.-L., et al., 1H NMR-based metabonomics of the hypoglycemic effect of polysaccharides from Cordyceps militaris on streptozotocin-induced diabetes in mice. Natural Product Research, 2018. 34(10): p. 1366-1372.

[9] Wang, K., et al., A novel class of alpha-glucosidase and HMG-CoA reductase inhibitors from Ganoderma leucocontextum and the anti-diabetic properties of ganomycin I in KK-A(y) mice. Eur J Med Chem, 2017. 127: p. 1035-1046.

[10] Zhang, Q., et al., Cytoprotective Effect of Morchella esculenta Protein Hydrolysate and Its Derivative Against H2O2-Induced Oxidative Stress. Polish Journal of Food and Nutrition Sciences, 2019. 69(3): p. 255-265.

[11] Roszczyk, A., et al. Immunomodulatory Properties of Polysaccharides from Lentinula edodes. International Journal of Molecular Sciences, 2022. 23, DOI: 10.3390/ijms23168980.

[12] Ren, L., J. Zhang, and T. Zhang, Immunomodulatory activities of polysaccharides from Ganoderma on immune effector cells. Food Chemistry, 2021. 340: p. 127933.

[13] Li, J., et al., Purification, structural characterization, and immunomodulatory activity of the polysaccharides from Ganoderma lucidum. International Journal of Biological Macromolecules, 2020. 143: p. 806-813.

[14] Zeng, D. and S. Zhu, Purification, characterization, antioxidant and anticancer activities of novel polysaccharides extracted from Bachu mushroom. International Journal of Biological Macromolecules, 2018. 107: p. 1086-1092.

[15] Datta, H.K., et al., Structural elucidation of a heteropolysaccharide from the wild mushroom Marasmiellus palmivorus and its immune-assisted anticancer activity. Carbohydrate Polymers, 2019. 211: p. 272-280.

[16] Wang, M. and F. Yu, Research Progress on the Anticancer Activities and Mechanisms of Polysaccharides From Ganoderma. Frontiers in Pharmacology, 2022. 13.

[17] Wen, L., et al., Structure of water-soluble polysaccharides in spore of Ganoderma lucidum and their anti-inflammatory activity. Food Chemistry, 2022. 373: p. 131374.

[18] Liu, X., et al., Antioxidant and hepatoprotective activities of residue polysaccharides by Pleurotus citrinipileatus. International Journal of Biological Macromolecules, 2019. 131: p. 315-322.

[19] Zhu, Y., et al., Antioxidant and anti-aging activities of polysaccharides from Cordyceps cicadae. International Journal of Biological Macromolecules, 2020. 157: p. 394-400.

[20] Lu, A., et al., Preparation of the Auricularia auricular polysaccharides simulated

hydrolysates and their hypoglycaemic effect. International Journal of Biological Macromolecules, 2018. 106: p. 1139-1145.

[21] Niu, B., et al., Moisture and caking resistant Tremella fuciformis polysaccharides microcapsules with hypoglycemic activity. Food Research International, 2021. 146: p. 110420.

[22] Liu Zhaoxi, Wang Lushan, and Chen Min, "Gut microbiota polysaccharide utilization and metabolism," Acta Microbiologica Sinica, 2021, 61(07): p. 1816-1828.

[23] Lin Ping and Shu Qinglong, "Research progress on pharmacological effects of Chinese medicine based on 'butyrate-producing bacteria-Chinese medicine polysaccharides'," Chinese Journal of Experimental Traditional Medical Formulae, 2020, 26(12): p. 219-226.

[24] Tang Yuan and Xie Guozhen, "Research progress on the interaction between polysaccharides and gut microbiota," Modern Agricultural Science and Technology, 2020(09): p. 225-227.

[25] Wang Haisong and Ren Pengfei, "Regulatory effects of oligosaccharides with different monosaccharide compositions on human gut microbiota," Journal of Chinese Institute of Food Science and Technology, 2020, 20(07): p. 44-52.

[26] Miao Jingnan, et al., "Research progress on edible and medicinal fungal polysaccharides regulating gut microbiota," Journal of Food Safety and Quality, 2021, 12(13): p. 5341-5348.

[27] Ma Gaoxing, et al., "Effects of different extraction processes on structural characteristics and immune activity of Pleurotus eryngii polysaccharides," Food Science, 2022, 43(17): p. 42-49.

[28] Kang Jie, "Effects of sweet cherry polyphenols and Pleurotus eryngii polysaccharides and flavonoids on hyperlipidemia and obesity model mice," 2021, Shanxi Agricultural University.

[29] Wang Danyang, et al., "Extraction of flavonoids from Pleurotus eryngii and study on their antioxidant activity," Farm Products Processing, 2020(19): p. 14-20.

[30] Zhao Yuanyuan, "Extraction, purification, structural characterization and lipid-lowering activity of polysaccharides from Pleurotus eryngii fruiting bodies," 2020, Shaanxi University of Science and Technology.

[31] Chen Jinjin and Feng Jiacheng, "Study on anti-fatigue activity of Pleurotus eryngii polysaccharides," Edible Fungi of China, 2020, 39(04): p. 46-48.

[32] Xiang Chaozong and Yang Xiaoqing, "Anti-exercise fatigue mechanism of Pleurotus eryngii polysaccharides," Edible Fungi of China, 2020, 39(03): p. 37-40.

[33] Tao Jie, "Analysis of antioxidant activity and nutritional value of Pleurotus eryngii polysaccharides in exercise," Edible Fungi of China, 2020, 39(02): p. 64-65+69.

[34] Ma, G., et al., Preparation of newly identified polysaccharide from Pleurotus eryngii and its anti-inflammation activities potential. J Food Sci, 2020. 85(9): p. 2822-2831.

[35] Zhang, C., et al., Antioxidant and anti-ageing effects of enzymatic polysaccharide from Pleurotus eryngii residue. International Journal of Biological Macromolecules, 2021. 173: p. 341-350.

[36] Wei Hua, "Hypolipidemic function of Pleurotus eryngii mycelium solid-state fermented polysaccharides and their effects on gut microbiota," 2018, Nanjing Normal University.

[37] Ma Gaoxing, "Effects of Pleurotus eryngii polysaccharides on intestinal immune function and its mechanism," 2018, Nanjing Agricultural University.

[38] Zhang Lina, et al., "Study on antioxidant and anticancer properties of Hericium erinaceus components and extracts," Food Industry, 2022, 43(06): p. 164-168.

[39] Wang Chenfang, et al., "Effects of Hericium erinaceus polysaccharides on microstructure, immune function, cell proliferation and apoptosis in thymus and spleen of immunologically stressed mice," Chinese Journal of Food Hygiene, 2022, 34(03): p. 482-490.

[40] Yan Jin, "Component analysis and physiological activity study of germanium-enriched Hericium erinaceus," 2022, Guizhou University.

[41] Chen Weihua, et al., "Study on the anti-lung adenocarcinoma effect of Hericium erinaceus polysaccharides combined with cisplatin," Medical Diet and Health, 2022, 20(01): p. 12-15.

[42] Saitsu, Y., et al., Improvement of cognitive functions by oral intake of <i>Hericium</i><i> erinaceus </i>. Biomedical Research, 2019. 40(4): p. 125-131.

[43] Hu Wenji, Study on the Anti-Alzheimer's Activity of Purified Polysaccharides from Fermented Mycelium of Hericium Erinaceus. 2021, Jilin University.

[44] Chang Yongshan, Research on the Anti-Fatigue Effect of Monkey Head Mushroom Sports Drinks %J Food Safety Guide. 2021(09): p. 62-63.

[45] Yizhe, Z., et al., Effects of Hericium erinaceus Hedgehog mushroom on the endophytic microbial community of the host plant. %J Journal of basic microbiology. 2022.

[46] Yang Jie, et al., Research Progress on the Health Benefits of Polysaccharides from Hericium erinaceus %J Agricultural Product Processing. 2021(12): p. 79-80+85.

[47] Yang Yang, Structural Analysis of Polysaccharides from Hericium Erinaceus and Research on Their Mechanism of Improving Intestinal Flora and Immunomodulatory Activity. 2021, Jilin University.

[48] Tian, B., et al., Digestive Characteristics of Hericium erinaceus Polysaccharides and Their Positive Effects on Fecal Microbiota of Male and Female Volunteers During in vitro Fermentation. Front Nutr, 2022. 9: p. 858585.

[49] Zhu Baiyu, et al., "Analysis of functional components and evaluation of in vitro antioxidant and hypoglycemic activities of Ganoderma from Kangding," Science and Technology of Food Industry: p. 1-18.

[50] Liu Yang, et al., "Research progress on hepatoprotective effects of Ganoderma," Special Wild Economic Animal and Plant Research: p. 1-7.

[51] Qin Junliang and Su Zhiheng, "Exploring the immunomodulatory mechanism of Ganoderma based on network pharmacology and molecular docking," Chinese Journal of New Clinical Medicine, 2022, 15(06): p. 522-527.

[52] Yu Xiaofeng, et al., "Comparative study on immune-enhancing effects of Ganoderma ultrafine powder from different soil cultivations in mice," Ginseng Research, 2022, 34(03): p. 2-4.

[53] Ma Chuangui, et al., "Active components of Ganoderma and research progress on its antitumor effects," Edible and Medicinal Mushrooms, 2022, 30(02): p. 114-118.

[54] Ding Qiao, "Mechanism of black Ganoderma polysaccharides on type 2 diabetic rats based on gut microbiota," 2020, Nanchang University.

[55] Chen, L., et al., Polysaccharides isolated from Cordyceps Sinensis contribute to the progression of NASH by modifying the gut microbiota in mice fed a high-fat diet. PLoS One, 2020. 15(6): p. e0232972.

[56] Chang, C.J., et al., Corrigendum: Ganoderma lucidum reduces obesity in mice by modulating the composition of the gut microbiota. Nat Commun, 2017. 8: p. 16130.

[57] Li Chuang, et al. Effects of Dietary Enoki Mushroom Bran Addition Level on Egg-laying performance, egg Quality and Serum biochemical and Antioxidant Indexes of Linwu Ducks aged 22-31 weeks. Chinese Journal of Animal Nutrition: p. 1-10.

[58] Hou Quan, Research on the Regulation and Mechanism of Cysteine Treatment on the Senescence Process of Postharvest Enoki Mushrooms. 2022, Zhejiang Gongshang University.

[59] Shen Cheng, et al., Effects of Fermented Enoki Mushroom Bran on Production

Performance, Immune Performance and Antioxidant Performance of Fattening Pigs. Porcine Science, 2022. 39(04): p. 84-85.

[60] Liu Xuecheng, et al., Food Science of Dietary Fiber Modification, Physicochemical Properties and Antioxidant and Lipid-lowering Activities of Enoki Mushrooms, 2021. 42(23): p. 90-98.

[61] Su Anxiang, Research on the Memory Improvement Mechanism of Enoki Mushroom Polysaccharides Based on Regulating the Structure of Intestinal Flora. 2019, Nanjing Agricultural University.

[62] Liang, Q., et al., The Effect of Flammulina velutipes Polysaccharide on Immunization Analyzed by Intestinal Flora and Proteomics. Front Nutr, 2022. 9: p. 841230.

[63] Xing Lei, Xing Wenwen, and Zhang Shuhong, "Exploring the mechanism of Cordyceps sinensis in treating diabetic nephropathy based on network pharmacology," Chinese Journal of Convalescent Medicine, 2022, 31(04): p. 358-363.

[64] Liu Xin, et al., "Exploring the antitumor mechanism of Cordyceps sinensis based on network pharmacology and molecular docking," Drugs & Clinic, 2022, 37(03): p. 483-492.

[65] Wu Huan, et al., "Exploring the mechanism of Cordyceps sinensis in treating colon cancer based on network pharmacology," Clinical Journal of Chinese Medicine, 2021, 13(29): p. 16-21.

[66] Wang Fang and He Weiming, "Traditional Chinese medicine understanding and pharmacological research progress of Cordyceps sinensis in treating chronic kidney disease," Journal of Practical Traditional Chinese Internal Medicine, 2021, 35(11): p. 135-138.

[67] Fang Qiuyue, et al., "Mechanism of different components of natural Cordyceps sinensis on intestinal injury repair in mice," Journal of Nanchang University, 2021, 45(03): p. 251-256.

[68] Chen Shuping, "Protective effects and mechanism of natural Cordyceps sinensis polysaccharides on intestinal health," 2021, Nanchang University.

[69] Ying, M., et al., Cultured Cordyceps sinensis polysaccharides modulate intestinal mucosal immunity and gut microbiota in cyclophosphamide-treated mice. Carbohydr Polym, 2020. 235: p. 115957.

[70] Yu Ling, "Preliminary study on the anti-photoaging effect of Tremella fuciformis polysaccharides," Fujian Textile, 2022(09): p. 11-14.

[71] Luo Xing, et al., "Physicochemical properties and antioxidant and antibacterial activities

of melanin from Tremella fuciformis spent substrate," Mycosystema: p. 1-21.

[72] An Xingliang, et al., "Optimization of extraction process of Tremella fuciformis polysaccharides by response surface methodology and study on their antioxidant and moisturizing properties," Food Research and Development, 2022, 43(15): p. 123-130.

[73] Xu Xiaofei, et al., "Comparison of anti-aging effects of two Tremella fuciformis polysaccharides in mice," Acta Edulis Fungi, 2022, 29(02): p. 93-102.

[74] Zhao Mingyue, et al., "Study on the effects of hyaluronic acid and Tremella fuciformis polysaccharides on D-galactose-induced aging mice," China Food Additives, 2021, 32(12): p. 1-8.

[75] Xu Xiaofei, et al., "Study on the improvement effect and mechanism of collagen peptide and Tremella fuciformis polysaccharides on skin of aging mice," Science and Technology of Food Industry, 2022, 43(08): p. 357-364.

[76] Liu Guangrong, et al., "Optimization of extraction process of Tremella fuciformis polysaccharides and their protective effect on SDS-induced HaCaT cell damage," Edible Fungi of China, 2021, 40(01): p. 97-102.

[77] Song Siyuan, et al., "Protective effect of Tremella fuciformis polysaccharides on intestinal microbiota in immunosuppressed mice," Chinese Journal of Microecology, 2020, 32(07): p. 772-776.

[78] Wang Zhaojing, Luo Dianhui, and Zeng Yawei, "Study on physicochemical characteristics, microstructure, antioxidant and anti-inflammatory effects of four Tremella polysaccharides," Chinese Pharmaceutical Journal, 2019, 54(21): p. 1788-1793.

[79] He, G., et al., Tremella fuciformis polysaccharide reduces obesity in high-fat diet-fed mice by modulation of gut microbiota. Frontiers in Microbiology, 2022. 13.

[80] Xie, L., et al., Tremella fuciformis polysaccharides alleviate induced atopic dermatitis in mice by regulating immune response and gut microbiota. Front Pharmacol, 2022. 13: p. 944801.